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IGNITION AND COMBUSTION - LOW COMPRESSION RATIO, HIGH OUTPUT DIESEL

(NASA-CR-169742) IGNITION AND COMBUSTION: LOW COMPRESSION RATIO, HIGH OUTPUT DIESEL Final Report, Sep. 1979 - 30 Apr. 1979 (Michigan Univ.) 43 p HC A03/MF A01 N83-15309
Unclas
G3/07 08039

FINAL REPORT OF PROJECT CONDUCTED
UNDER NASA GRANT NO. NSG 3161

PERIOD OF GRANT AND REPORT: SEPTEMBER 1978 TO
APRIL 30, 1979

WORK DONE BY:
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JULY 1981

Table of Contents

I. Introduction and Objectives

This project was undertaken as a sequel to an earlier NASA contract project entitled, "Lightweight, Low Compression Aircraft Diesel Engine," carried out under NASA contract No. NAS 3-20051, under the direction of R. A. Kroeger of the Aerospace Department, College of Engineering, University of Michigan. Further details concerning this preceding project are given on the title sheet of the Report No. CR-135300, which is included herewith as Appendix A, and in reference 1*.

This grant was made to determine the feasibility of converting a spark-ignition aircraft engine GTSIO-520 to compression ignition without increasing the peak combustion pressure of 1100 lbs/sq.in. The final engine contemplated was to utilize intake air heating at idle and light load and a compression ratio of about 10:1 with a small amount of "fumigation" (the addition of about 15% fuel into the combustion air before the cylinder).

The engine used was a modification of a Continental-Teledyne gasoline engine cylinder from the GTSIO-520 supercharged aircraft engine.

II. Summary of Results

The normal process of development of the new test apparatus and of methods of test, coupled with some personnel problems, used the dollar budget(1) to such an extent that the combustion development remains about 4 months short of completion.

*Numbers refer to those listed in bibliography.

(1) The original cost estimate made at the University of Michigan to do the work was considerably greater than the amount NASA had available. Nevertheless, the work was undertaken on the basis that there would be a minimum of unplanned trouble. The test equpment "debugging", of course, was unexpected and this is explained on the basis that the cell needed to be revised more than expected because of increase in power for the 520 over the previous engine used in the test cell.

The reliable data taken on the last days of test indicate that the air utilization was poor, probably because the factors of air swirl(2) in the combustion chamber, injection of the fuel into the combustion volume, and fuel injection timing had not been optimized (note Figure 4), page 9. See cruise power table comparison, Table 1, page 5, which shows that 70% more air was required for equal power compared to the standard spark ignition engine whereas comparable well-developed diesels require about 33% more. We believe that a greater cut-and-try effort will yield the required improvement. The test conditions and performance for take-off power have not been evaluated in this work so far. The converted standard spark-ignition cylinder essentially withstood the testing without mechanical trouble even though some data points were obtained with 1300 lbs/sq.in. peak combustion pressure.

As suggested above, there were many changes in equipment and improvements in the accuracy of the measurements as the work progressed. Some of these modifications are indicated on Figure 1, which shows hours of engine operating time as a function of calendar date. The result of all this is that we have little confidence in most of the data taken. For this reason only the performance data of Figure 2, and the tabulated comparison shown on Table 1, page 5, have been included. These data were taken near the end of the grant period, and represent values which we believe to be most reliable. However, even these data points should be re-run to give confidence in them.

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(2) There is a considerable literature on the importance of air swirl and of air turbulence in utilizing air in the combustion space and a recent reference is SAE 810477, especially SAE 810255, and the list of references given in this paper.

Table 1

Comparison of Continental Aircraft Engine GTSIO-520F
and Best Performance of NASA Experimental Diesel Cylinder

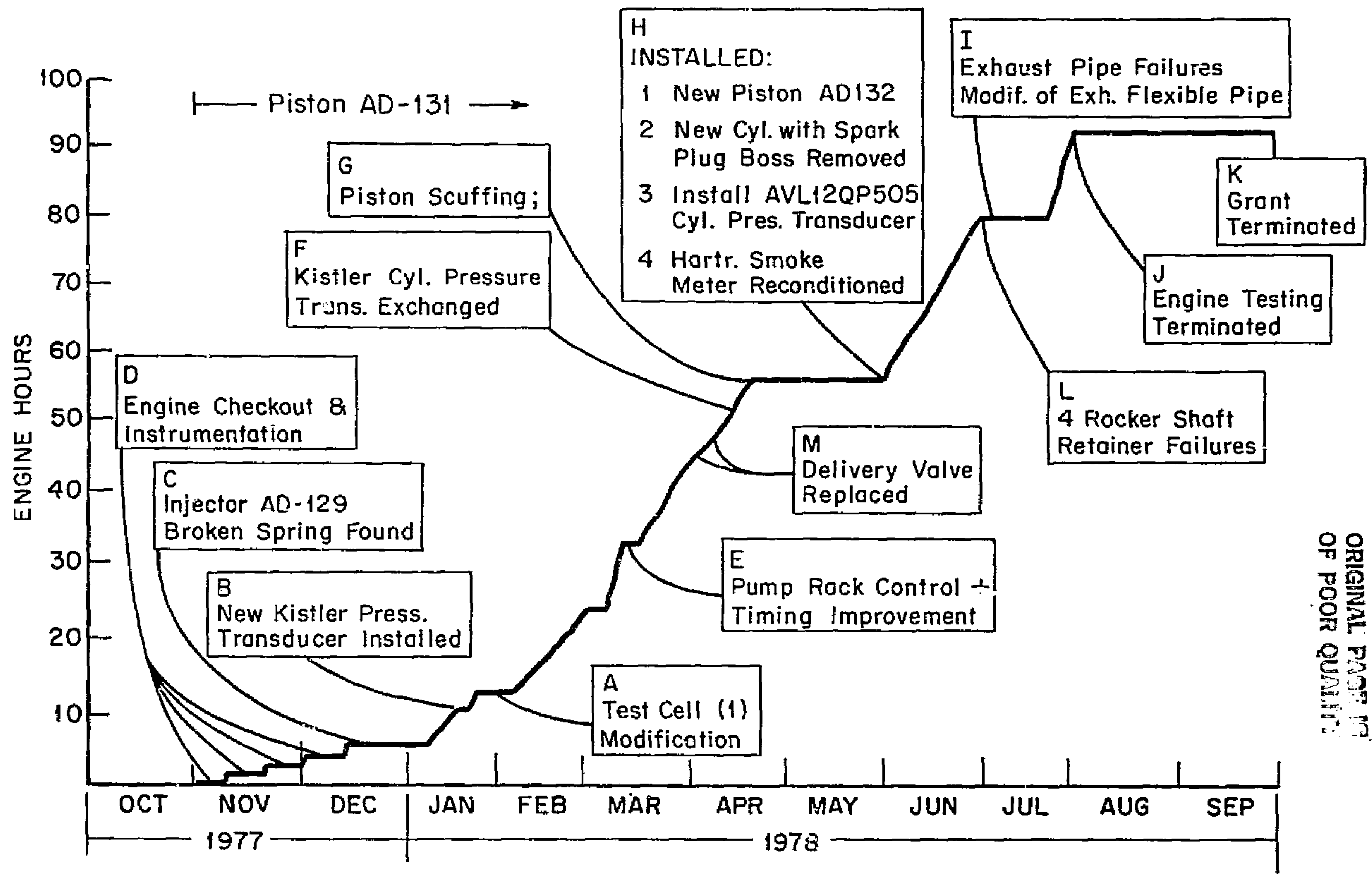
Cruise Power

(75% x 435 = 324 BHP at 2900 rpm = 170.2 BMEP)

	GTSIO-520F			Diesel	
				Goal	Present
Compression ratio	7.5	7.5	7.5	10	9.62
RPM	2900	2900	2900	3040	2600
Fuel/Air	.065 (1)	0.77	.088	.038	.039
Brake Sp. Fuel Cons.,lbs/BHP-hr	.43	.48	.55	.42	.396 (2)
Indicated Fuel Cons.,lbs/BHP-hr				.39	.356
Peak Comb. Press, lbs/sq.in.				1100.	1200.
Press. Rise Rate, psi/ca				300	186
Brake MEP, lbs/sq.in.				180	188 (2)
Indicated MEP, lbs/sq.in.				200	209
Exh. Temp, ^oF	1700	1600	1500	1500	1355
Intake Temp., ^oF	192	192	192	200	165^oF
Cyl. Head Temp., ^oF				400	386
Smoke Hartridge				10	11.5
Cooling Air Press. Drop "H_2O				6.0	6.0
Intake Air Press. In.Hg.Abs.	36	36	36	53	70
Exh. Press. In.Hg.Abs.				38	50
Air Utilization, lbs.Air/BHP.hr.		[illegible].16		8.8	10.5 (2)
Air Density, lbm/ft^3					0.151
Reference	GTSIO-520-F Report No. 629 14 July 70				July 24-78

(1) Operation at this F/A is not recommended because detonation margin is small and because of higher cylinder head temperatures.

(2) Mech. Eff. = 90% - (based on friction HP curve for GTSIO-520)



-6-

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(1) Scope, Needle Lift Trans., Poloroid, New Fuel Weigh, Replace Toledo with Link-Hartridge.

Fig. 1. Engine firing time and Modifications, as function of date.

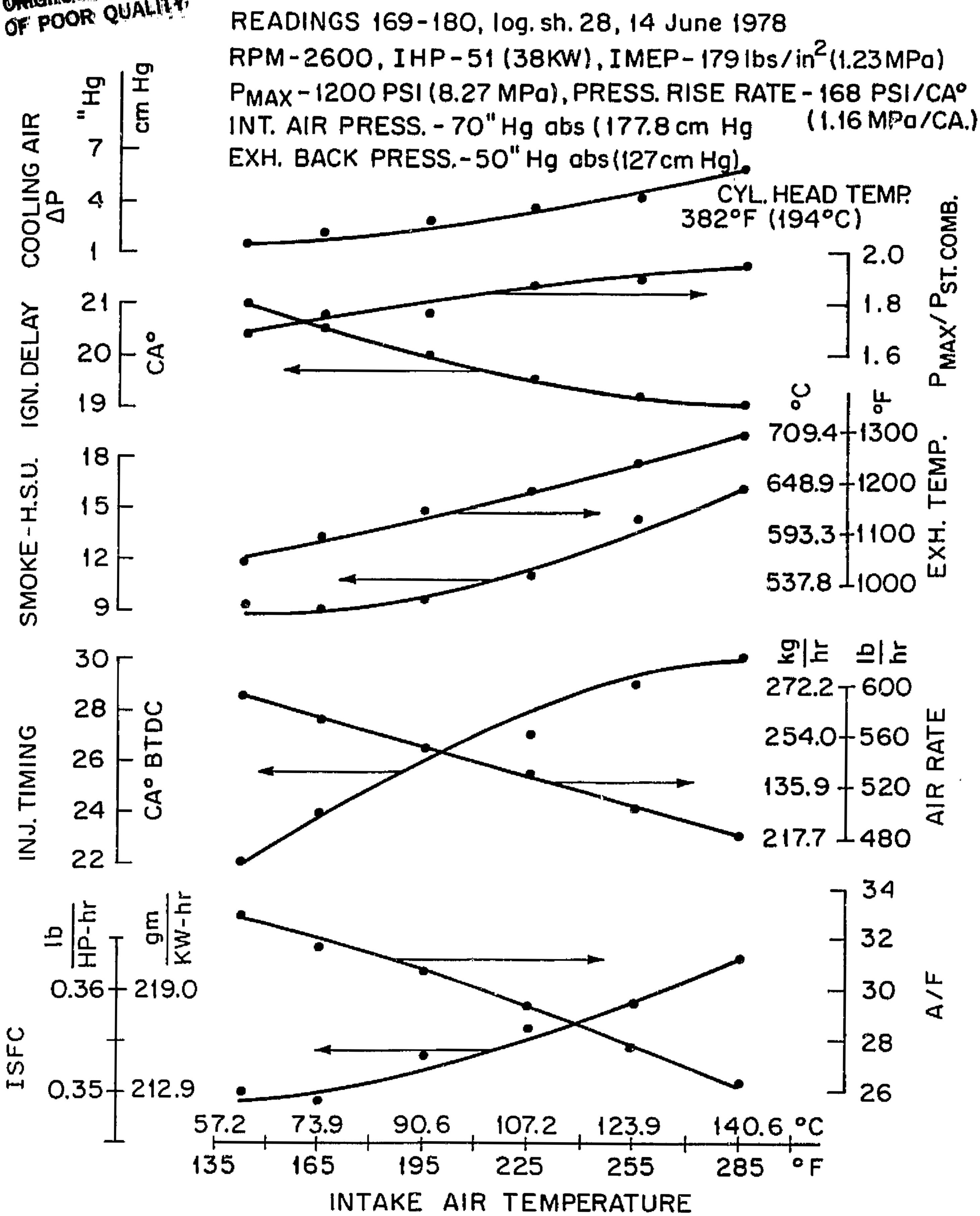

Fig. 2. Best performance obtained from GTS 10-520F modified diesel cylinder.

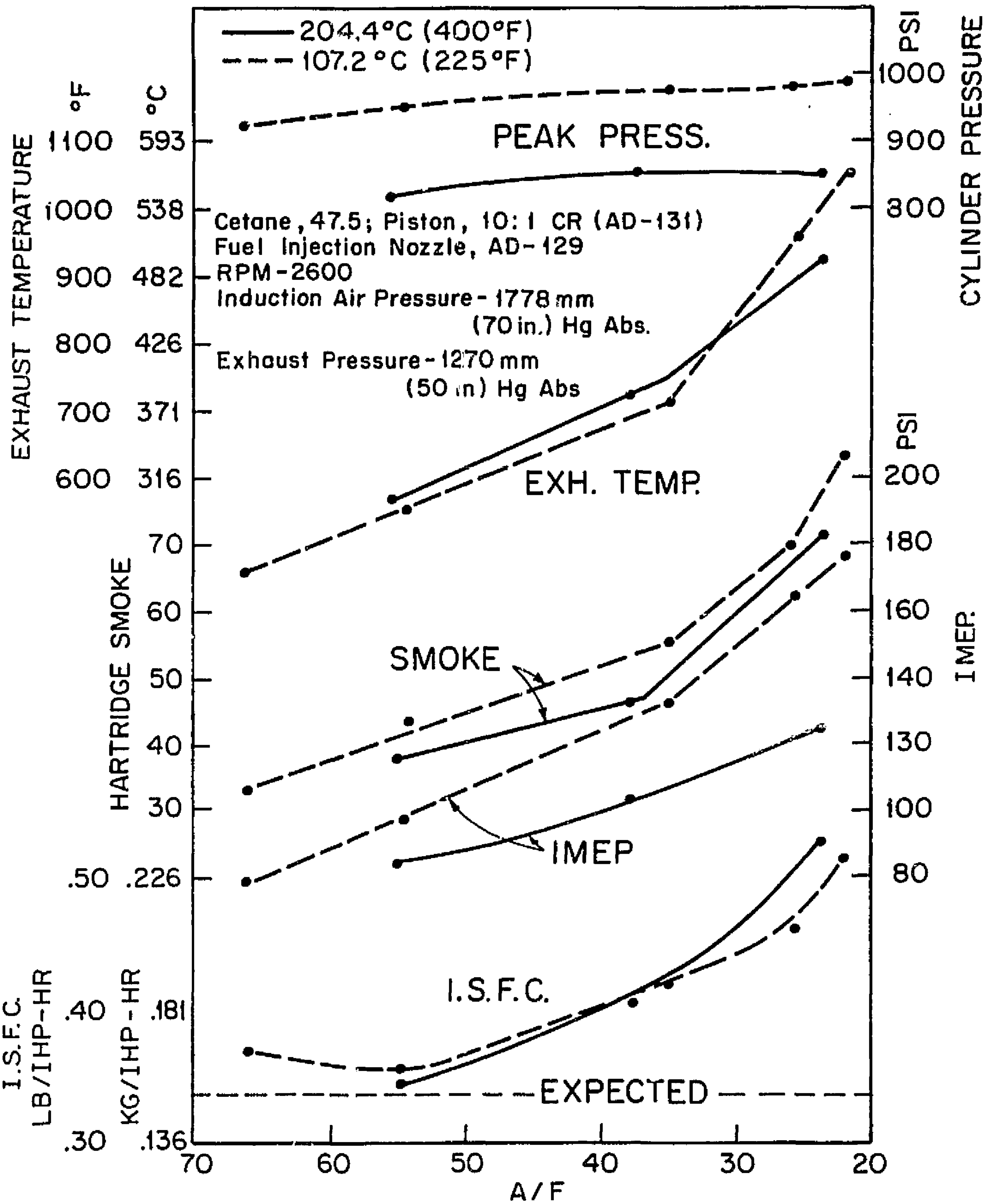

Fig. 3. Engine performance from Ref. 1, earlier NASA contract.

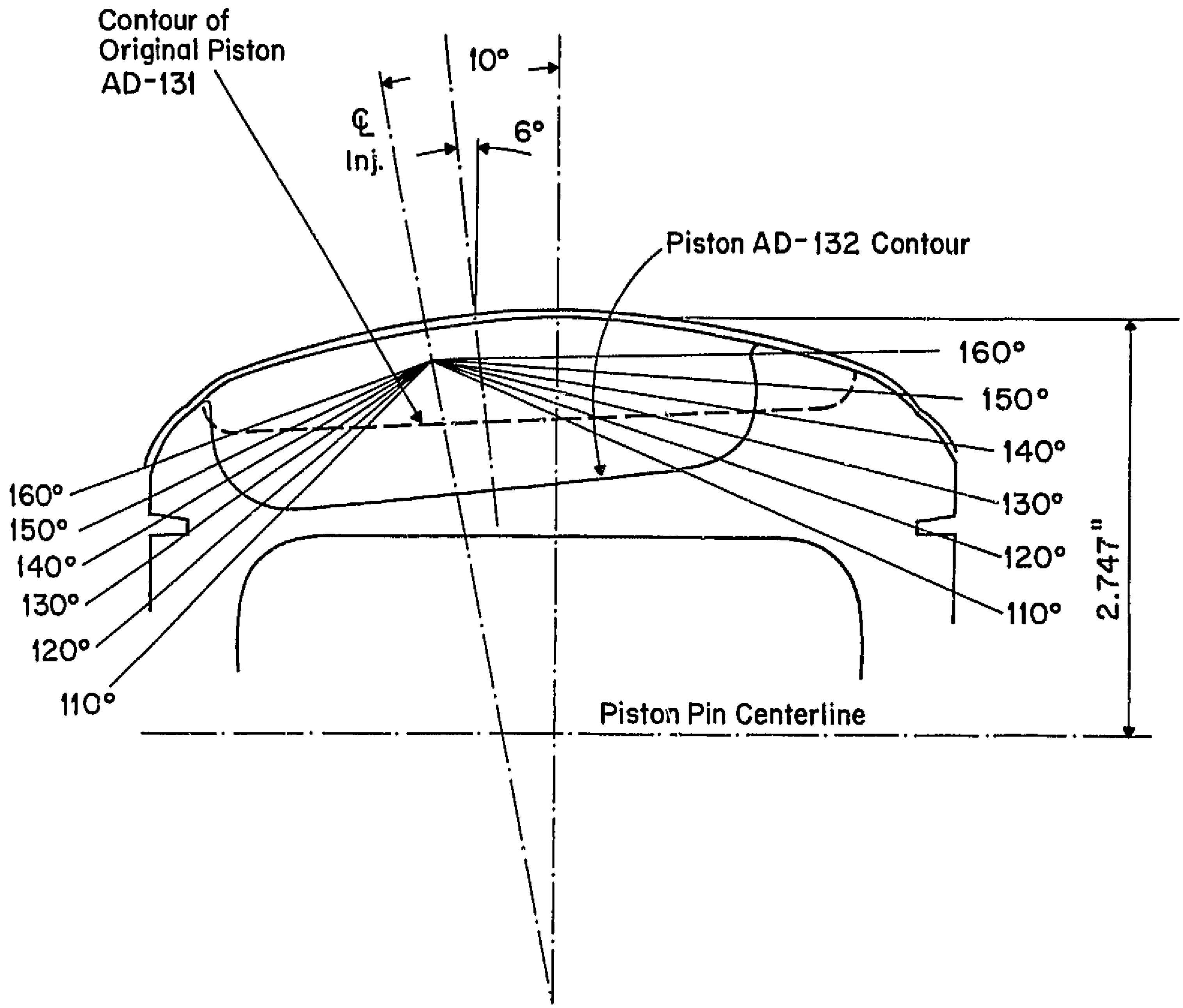

Fig.4. Nozzle hole angles related to pistons AD-131 and AD-132 top contours.

The best results at the cruise condition obtained from our single-cylinder tests are shown on Figure 2. This is in comparison with the data shown on Figure 3, which is a reproduction of Figure 29, taken from reference 1, Report No. CR-135300. Table 2 below compares some of the significant values. It will be noted that substantial gains were accomplished in improving fuel economy and reducing smoke.

The results of the computer simulation programs are given in a following section.

Table 2

Comparison of Single Cylinder Test Engine Performance at Maximum Output of 1977 Contract (Ref. 1) with Present Grant Best Performance Conditions:

RPM	2600.
Intake air temperature, °F	225
Intake air pressure	70" Hg.
Exhaust pressure	50" Hg.
Test run No.	174

Ind. M.E.P.		Ind. SFC (lbs/ind. HP-hr)		Smoke Hartridge H.S.U.	
1977	1979	1977	1979	1977	1979
175	179	.51	0.356	80	11.5

III. Equipment Changes and Improvements

During the period of this grant many test cell modifications, equipment changes and improvements have been made. See Figure 1 - Engine Firing Time vs. Date (for the date when these changes were made). The list of major changes and modifications which follow are indicative of the problems which occurred.

1. The pressure transducers for the cylinder pressure (Kistler-type 6005) and for the fuel line pressure (Kistler-type 607 FX) were recalibrated several times.

2. The two-trace oscilloscope was replaced by a four-trace Tektronix oscilloscope to allow simultaneous recording of: cylinder pressure, fuel line pressure, needle lift, and crank angle degree marks.

3. The needle lift instrument installation was improved following a visit to the Stanadyne Co., Hartford, Connecticut, where many details were discussed. The previous installation used during the earlier contract resulted in broken injection springs and plugging of several nozzle holes of the injector AD-129 which was in the engine at the start of this grant. The broken spring is suspected to be the reason for the extremely high smoke (70 and 80 H.S.U) and high specific fuel consumption (0.51 and 0.52 lb/hp-hr) of Figure 3 from Report CR-135300).

4. The appropriate polaroid camera was reconditioned and installed on the oscilloscope.

5. It was found that the scale beam readings were more steady without use of the engine automatic speed control device. A spring was installed in the pump rack control linkage to insure constant rack

position during test runs. To measure rpm, a total revolution counter was synchronized with the fuel weighing timer.

6. A new fuel weighing device was incorporated into the equipment set-up to improve the precision of fuel measurement.

7. The leak-off of the injector was ducted back to the fuel measuring beaker, to avoid error from such leakage.

8. Two additional temperature indicators were installed for direct measurement of cylinder head and exhaust gas temperature.

9. A new air pressure regulating valve was installed in the air supply system which resulted in less fluctuation of the engine intake air pressure.

10. The cylinder pressure transducer was mounted flush with the inner combustion chamber wall by means of a new adapter.

11. The thermocouple probe for the exhaust temperature was found to be burned and was replaced.

12. The Toledo gear-weighted pointer dynamometer load measuring unit was replaced by a Link-Unibeam System to (a) eliminate need for observer to average pointer reading variation due to vibration of pointer, (b) increase scale length when reading engine friction, (c) to prevent destruction of the gear teeth of the Toledo unit.

13. A fuel leak near the base of the fuel line pressure transducer holder was repaired.

14. The Hartridge smokemeter showed inconsistent readings and was reconditioned by the factory authorized service.

15. A new AVL water-cooled quartz pressure transducer No. 12QP505 with special temperature compensation, and with a shield, was installed for reduced radiant heat effects. The pressure unit was also suspect because of zero pressure uncertainty.

16. At higher engine speeds, the flexible exhaust hose failed several times and it was necessary to modify the exhaust system by lowering the exhaust surge tank and thus eliminate the bending and resultant stress of the flexible hose between the cylinder and the tank.

IV. Difficulties with and Changes made in Engine

During the period of November 1, 1977 through July 31, 1978, several engine-related difficulties were encountered, and corresponding changes and/or improvements were made, as follows:

1. After several introductory runs of the engine in search of the cause of the very dark exhaust (70 Hartridge units) and poor performance, injector AD-129 was taken out and dismantled. The injector spring was broken in four pieces and several spray holes were plugged with carbon. The manufacturer of the nozzle, Stanadyne, suggested that the most probable cause of that failure was improper installation of the needle lift instrumentation. The nozzle was not repairable due to long operation with the broken spring.

2. Mechanical pointers with positive locking devices for the injection timing and rack linkages were fabricated and installed on the Bosch APE1B fuel pump, which eliminated slight creeping of the hydraulic controls.

3. The high pressure fuel line (Bosch pump-injector) was replaced with one having 0.078 in. inside diameter instead of previous one with 0.083 in. inside diameter. This reduced some minor after-injection.

4. When an effort was made to increase the load of the engine at cruise power output, after-injection was again encountered. After experimenting with four delivery valves we found that the valve (Bosch special design X2708) with retraction volume of 65 mm^3 eliminated the after injection and all test

runs after mid-April of 1978 were done with that valve. All prior test runs were done with the Bosch valve X2615 (50 mm^3 retraction volume).

5. After a short period of engine running at cruise power output, excessive blowby was observed. Teardown of the engine revealed that piston AD-131 was badly scuffed. Teledyne-Continental Motors in Mobile, Ala. examined the piston-cylinder assembly, and found that the top piston ring had only 0.001 in. side clearance instead of the normal clearance of 0.004 in., and concluded that this was the main cause of the piston scuffing. It was also suggested that we reduce the upper piston land diameter of 5.216/5.215 inches by about 0.005 inches, due to the piston being slightly higher than the original GTS10-520 piston and possible higher temperatures at the piston top.

6. The support or retainer of the rocker arm shaft on the exhaust valve failed four times. After the first failure it is possible that the Helicoil was damaged and that all subsequent failures occurred because of the damaged Helicoil thread which caused low bolt holding force and resulted in a high stress range in the bolt threads. Teledyne-Continental Motors does not have a history of such failures, and it is believed that the fault should not be ascribed to the diesel combustion.

V. COMPUTER SIMULATION OF DIESEL CYCLE

A sub-task of this study was to develop a simple computer simulation of the diesel cycle with the objective that it would aid in correlating the experimental data and could then be used to extrapolate to conditions which indicate improved engine performance.

Two programs were developed during this study. The first, DIESELA, gives predicted engine performance parameters

IMEP	indicated mean effective pressure,
ISFC	indicated specific fuel consumption,
IEFF	indicated thermal efficiency, and
IHP	indicated horsepower

based on input values for

A/F	air-fuel ratio,
CR	compression ratio,
T1	temperature at the start of compression,
P1	intake manifold pressure, and
P6	exhaust pressure.

A limiting peak pressure of 1200 psia and a compressio ratio of 9.62, which correspond to the experimental test conditions, were used in all cases examined.

A second program, DIESELB, was started in order to improve the simulation of the constant volume and constant pressure combustion processes. It is based on calculated equilibrium conditions for the ends of the ideal constant volume and constant pressure combustion processes. The objective was to calculate the thermodynamic properties at these states rather than rely on the use of average specific heats derived from combustion chart data.

1. Program DIESELA

This simulation is based on a semi-empirical model which starts with the ideal cycle shown in Fig. 5 and then applies semi-empirical factors in an attempt to bring the model results into better agreement with measured engine data. Details of the model are as follows:

(a) The temperature at the beginning of the compression stroke (T1) is assumed to be equal to that measured in the intake manifold. The corresponding pressure (P1) is taken to be equal to the intake manifold pressure (PI) times the volumetric efficiency. The initial charge is assumed to consist only of air.

(b) Mass of the initial charge at state 1 is obtained from the ideal gas equation and the assumed pressure and temperature conditions from (a) above. The volumetric efficiency equation is taken from Taylor and Taylor (vol. 1, p. 157). This equation was tested using calculated and measured air mass flow rates and the resulting equation shows the influence of engine RPM. Attempts to find effects of other parameters on volumetric efficiency showed no clear correlations.

(c) Compression (1-2) is assumed to follow the polytropic process PV^n = constant, where the value for the polytropic exponent was obtained from Continental Motors Report No. 1069, Aug. 1967. The report contains a plot which correlates data from a large number of engines and gives values of the polytropic exponent as a function of both maximum pressure and compression ratio.

(d) Heat addition at constant volume is calculated using:

$$Qv = M*Cv(aver)*(T3 - T2).$$

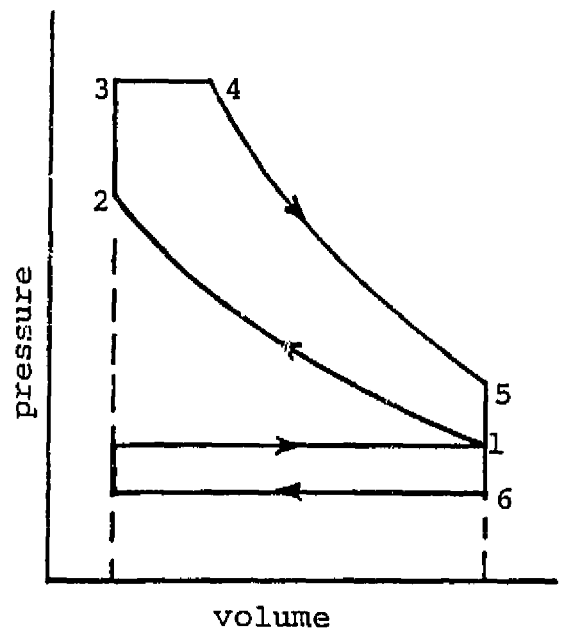

Fig. 5. Ideal Diesel Cycle

An adiabtic process is assumed and Cv(aver) is computed from combustion chart data for the temperature range T2 to T3, the value of T3 being dependent upon the selected maximum cycle pressure P3. The amount of mass (M) is that of the air charge plus the amount of fuel required to reach maximum pressure during the constant volume process. An iterative process is used to get compatible values for T3 and this fuel mass.

(e) Heat addition at constant pressure is used to determine state (4) using:

$$Qp = M*Cp(aver)*(T4 - T3),$$

where Qp is equal to the difference between the available heating value of the fuel and that released during the constant volume process. An average value for Cp is computed from combustion chart data for the temperature range T3 to T4, using an iterative procedure similar to that used in (d) above.

(f) Expansion (4-5) is assumed to follow a polytropic process having the same exponent used for the compression process.

(g) The remaining processes are:

(5-6) constant volume expansion to the pressure P6 in the exhaust manifold.
(---) constant pressure exhaust process.
(---) constant pressure intake process.

(h) Indicated work for the ideal cycle is compared with the indicated work obtained from experimental brake and friction work values. The ratio of the two indicated work quantities is defined as the "diagram factor".

starts at the beginning of the constant volume combustion process using results from DIESELA. These include:

T2	temperature at the end of compression.
P2	pressure at the end of compression.
V2	cylinder volume at the end of compression.
NA	moles of air in the fresh mixture.

The program then computes the state of the combustion gases resulting from adiabatic constant volume combustion and assumed equilibrium at the limiting peak pressure (P3). The fuel required for this process (FV) is calcululted and the remaining fuel (F-FV) is then consumed during the constant pressure combustion process. Equilibrium at the end of the constant pressure process is also computed.

The program listing for DIESELB, the corresponding list of symbols and a sample output are shown in the Appendix B. The sample output gives the following information:

CR	compression ratio.
T2	temperature at the end of compression in deg. K.
A/F	air-fuel ratio.
PMAX	limiting maximum pressure, (1200 psia).

For the constant volume process:

Y(J)	moles of specie J at equilibrium.
X(J)	mole fraction of specie J at equilibrium.
YTOT	total moles of products at state 3.
FUEL	moles of fuel used during the constant volume combustion process.

For the constant pressure process:

Y(J)	moles of specie J at equilibrium.
X(J)	mole fraction of specie J at equilibrium.
YTOT	total moles of produsts at state 4.

Diagram factors for forty-eight engine runs were obtained and correlations with various operating variables were tried. Only mixture ratio was found to show a reasonable correlation.

(i) Application of the diagram factor to the ideal cycle calculations gives predicted performance of the engine under various operating conditions.

The program listing of DIESELA is given in the Appendix together with a listing of the nomenclature. The sample output, shown in Table IV, gives values for the following input engine conditions:

Pmax	T1
RPM	P1
A/F	P6
CR	

Computed values listed are:

T5	Deg F.
MV/MF	ratio of mass of fuel used during constant volume to the total mass of fuel per cycle.
DF	diagram factor = (calc IHP/exper IHP).
IMEP	indicated mean effective pressure.
ISFC	indicated specific fuel consumption.
IEFF	indicated thermal efficiency.
IHP	indicated horsepower.

2. Program DIESELB

This program attempts to improve the cycle simulation of the constant volume and constant pressure combustion processes by eliminating the need for combustion chart data. The program

VOL	gas volume at state 4.
T4	temperature at state 4 in deg K.
PRESS	pressure at state 4 in atmospheres.

Some additional work would be required to incorporate this program in the DIESELA simulation.

3. Computer Study Results

Results showing calculated versus measured ISFC are given in Fig. 6 and similar results for IHP are given in Fig. 7. Forty-eight test runs, taken at the end of the test program, were used in this comparison. Measured values are given in Table III while the corresponding computer results are shown in Table IV. The ranges of engine parameters covered in these test runs are:

CR	9.62 (Fixed)
RPM	2405 - 3007
A/F	19.15 - 32.90
T1	142 - 286 F
PI	59.4 - 79.4 "Hg.
P6	44.4 - 49.4 "Hg.

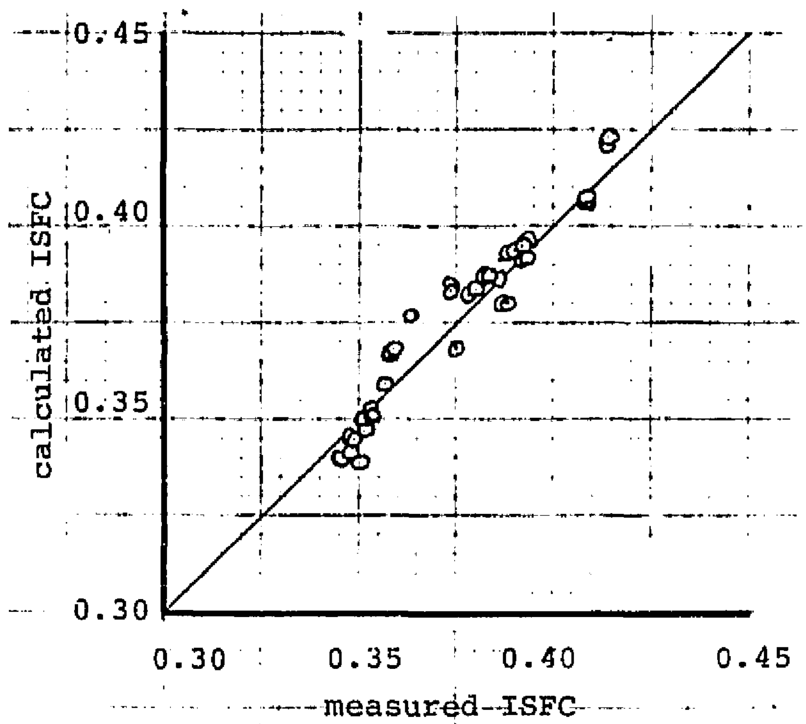

Fig. 6 - Calculated versus Measured Indicated Specific Fuel Consumption

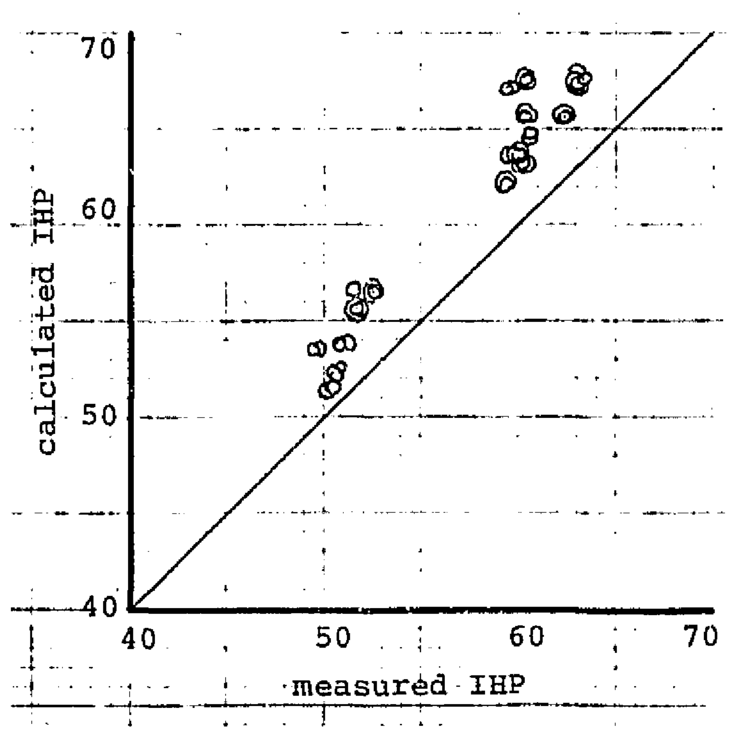

Fig. 7 - Calculated versus Measured Indicated Horsepower

Table 3 - Measured Engine Performance

RUN	RPM	A/F	T1	P1	P6	IMEP	ISFC	VE	IHP
169	2606	26.32	284	69.60	48.60	176.3	0.363	0.957	50.24
170	2600	26.38	284	69.60	48.60	176.5	0.363	0.958	50.16
171	2600	27.74	252	69.60	48.60	178.0	0.359	0.961	50.60
172	2600	27.82	252	69.60	48.60	177.8	0.358	0.962	50.53
173	2596	29.27	225	69.60	48.60	179.4	0.356	0.976	50.92
174	2598	29.33	226	69.60	48.60	179.1	0.356	0.977	50.87
175	2601	30.74	195	69.60	48.60	178.6	0.354	0.970	50.79
176	2602	30.59	195	69.60	48.60	180.1	0.353	0.970	51.24
177	2606	31.74	165	69.60	48.60	181.6	0.349	0.957	51.73
178	2605	31.77	164	69.60	48.60	181.6	0.348	0.956	51.72
179	2598	32.90	142	69.60	48.60	181.5	0.350	0.959	51.56
180	2598	32.90	142	69.60	48.60	181.5	0.350	0.959	51.56
190	2608	31.50	164	69.20	49.20	181.5	0.351	0.959	51.76
191	2604	31.73	164	69.20	49.20	181.0	0.350	0.960	51.51
192	2808	32.59	165	69.20	49.20	172.0	0.348	0.935	52.80
193	2804	32.89	162	69.20	49.20	172.1	0.345	0.931	52.76
194	2405	30.92	165	69.20	49.20	188.5	0.351	0.980	49.57
195	2409	30.96	165	69.20	49.20	189.1	0.351	0.984	49.80
196	2610	21.96	166	69.30	49.30	221.2	0.409	0.952	63.12
197	2607	22.02	166	69.30	49.30	221.1	0.409	0.953	63.00
198	2809	24.80	166	69.30	49.30	202.9	0.384	0.924	62.31
199	2811	24.67	166	69.30	49.30	203.1	0.383	0.919	62.41
200	3005	25.37	165	69.30	49.30	191.8	0.380	0.885	63.02
201	3007	24.98	165	69.30	49.30	191.7	0.386	0.983	63.00
200	3005	25.39	165	69.40	49.40	191.5	0.381	0.885	62.91
201	3007	25.03	165	69.40	49.40	191.7	0.386	0.883	63.00
202	2810	25.39	165	69.40	49.40	197.4	0.380	0.909	60.65
203	2805	25.52	165	69.40	49.40	197.8	0.378	0.910	60.65
204	2599	25.45	166	69.40	49.40	209.0	0.374	0.952	59.39
205	2603	25.28	166	69.40	49.40	208.7	0.374	0.944	59.39
206	2601	27.94	166	79.40	47.90	211.7	0.375	0.928	60.18
207	2601	27.95	166	79.40	47.90	211.7	0.375	0.927	60.19
208	2602	23.72	166	69.40	44.40	211.2	0.393	0.942	60.09
209	2605	23.78	165	69.40	44.40	211.6	0.391	0.939	60.27
210	2599	19.15	166	59.40	44.40	211.3	0.414	0.936	60.05
211	2601	19.18	166	59.40	44.40	211.0	0.414	0.935	60.01
212	2405	26.71	165	80.50	49.50	225.7	0.389	0.920	59.35
213	2412	26.72	165	80.50	49.50	226.3	0.387	0.917	59.68
214	2605	23.27	165	67.50	44.50	211.9	0.392	0.950	60.36
215	2610	23.24	164	67.50	44.50	211.8	0.392	0.947	60.44
216	2598	22.85	195	69.00	44.50	210.1	0.394	0.953	59.67
217	2602	22.85	195	69.00	44.50	210.0	0.394	0.951	59.75
218	2600	23.19	224	72.00	44.50	210.5	0.393	0.967	59.84
219	2603	23.17	224	72.00	44.50	210.3	0.393	0.965	59.87
220	2600	23.35	255	75.20	44.50	211.6	0.390	0.972	60.15
221	2603	23.37	255	75.20	44.50	211.5	0.390	0.972	60.19
222	2602	23.43	286	78.40	44.50	212.2	0.390	0.978	60.36
223	2603	23.49	285	78.40	44.50	212.4	0.388	0.976	60.44

Table 4 - Calculated Engine Performance

P3= 1200

RUN	RPM	A/F	CR	T1	T5	P1	P6	MV/MF	DF	IMEP	ISFC	IEFF	IHP
169	2606	26.32	9.62	284	1571	69.60	48.60	0.42	0.821	181.2	0.377	37.08	51.63
170	2600	26.38	9.62	284	1569	69.60	48.60	0.42	0.821	181.2	0.377	37.12	51.50
171	2600	27.74	9.62	252	1488	69.60	48.60	0.42	0.833	184.1	0.369	37.95	52.33
172	2600	27.82	9.62	252	1434	69.60	48.60	0.42	0.834	183.8	0.368	37.99	52.24
173	2596	29.27	9.62	225	1408	69.60	48.60	0.42	0.847	186.0	0.359	38.90	52.80
174	2598	29.33	9.62	226	1406	69.60	48.60	0.43	0.847	185.5	0.359	38.93	52.68
175	2601	30.74	9.62	195	1333	69.60	48.60	0.42	0.861	189.6	0.351	39.84	53.90
176	2602	30.59	9.62	195	1338	69.60	48.60	0.42	0.859	190.0	0.352	39.74	54.05
177	2606	31.74	9.62	165	1279	69.60	48.60	0.41	0.871	195.4	0.345	40.50	55.67
178	2605	31.77	9.62	164	1278	69.60	48.60	0.41	0.871	195.7	0.345	40.52	55.73
179	2598	32.90	9.62	142	1226	69.60	48.60	0.41	0.884	199.8	0.339	41.29	56.76
180	2598	32.90	9.62	142	1226	69.60	48.60	0.41	0.884	199.8	0.339	41.29	56.76
190	2608	31.50	9.62	164	1285	69.20	49.20	0.42	0.869	194.7	0.347	40.28	55.52
191	2604	31.73	9.62	164	1277	69.20	49.20	0.42	0.871	194.2	0.346	40.43	55.29
192	2808	32.59	9.62	165	1238	69.20	49.20	0.47	0.880	184.6	0.342	40.94	56.68
193	2804	32.89	9.62	162	1227	69.20	49.20	0.47	0.884	184.9	0.340	41.15	56.67
194	2405	30.92	9.62	165	1318	69.20	49.20	0.37	0.863	204.0	0.350	39.92	53.63
195	2409	30.96	9.62	165	1317	69.20	49.20	0.37	0.863	203.7	0.350	39.95	53.64
196	2610	21.96	9.62	166	1782	69.30	49.30	0.29	0.787	237.2	0.408	34.28	67.69
197	2607	22.02	9.62	166	1778	69.30	49.30	0.29	0.788	237.0	0.407	34.32	67.54
198	2809	24.80	9.62	166	1583	69.30	49.30	0.36	0.809	213.7	0.388	36.07	65.63
199	2811	24.67	9.62	166	1590	69.30	49.30	0.36	0.808	214.3	0.388	36.00	65.86
200	3005	25.37	9.62	165	1539	69.30	49.30	0.39	0.813	204.9	0.384	36.42	67.31
201	3007	24.98	9.62	165	1561	69.30	49.30	0.39	0.810	206.7	0.386	36.19	67.96
200	3005	25.39	9.62	165	1538	69.40	49.40	0.39	0.813	205.0	0.384	36.42	67.36
201	3007	25.03	9.62	165	1558	69.40	49.40	0.38	0.811	206.7	0.386	36.21	67.96
202	2810	25.39	9.62	165	1549	69.40	49.40	0.36	0.813	211.3	0.384	36.42	64.92
203	2805	25.52	9.62	165	1542	69.40	49.40	0.36	0.814	210.9	0.383	36.50	64.67
204	2599	25.45	9.62	166	1560	69.40	49.40	0.34	0.814	218.3	0.384	36.43	62.03
205	2603	25.28	9.62	166	1569	69.40	49.40	0.33	0.812	219.0	0.385	36.33	62.32
206	2601	27.94	9.62	166	1483	79.40	47.90	0.25	0.835	238.4	0.369	37.87	67.80
207	2601	27.95	9.62	166	1482	79.40	47.90	0.25	0.835	238.4	0.369	37.87	67.79
208	2602	23.72	9.62	166	1665	69.40	44.40	0.31	0.800	230.5	0.392	35.67	65.57
209	2605	23.78	9.62	165	1660	69.40	44.40	0.31	0.801	230.4	0.392	35.70	65.61
210	2599	19.15	9.62	166	1943	59.40	44.40	0.36	0.767	224.3	0.424	33.01	63.74
211	2601	19.18	9.62	166	1940	59.40	44.40	0.36	0.767	224.0	0.423	33.03	63.70
212	2405	26.71	9.62	165	1564	80.50	49.50	0.20	0.824	254.9	0.380	36.77	67.03
213	2412	26.72	9.62	165	1563	80.50	49.50	0.20	0.824	254.6	0.380	36.78	67.13
214	2605	23.27	9.62	165	1681	67.50	44.50	0.32	0.797	226.8	0.395	35.43	64.61
215	2610	23.24	9.62	164	1683	67.50	44.50	0.32	0.797	227.2	0.395	35.41	64.83
216	2598	22.85	9.62	195	1730	69.00	44.50	0.32	0.794	224.4	0.397	35.19	63.74
217	2602	22.85	9.62	195	1730	69.00	44.50	0.32	0.794	224.2	0.397	35.19	63.79
218	2600	23.19	9.62	224	1737	72.00	44.50	0.30	0.796	222.7	0.395	35.40	63.29
219	2603	23.17	9.62	224	1738	72.00	44.50	0.30	0.796	222.7	0.395	35.39	63.37
220	2600	23.35	9.62	255	1759	75.20	44.50	0.28	0.798	222.0	0.394	35.50	63.11
221	2603	23.37	9.62	255	1757	75.20	44.50	0.29	0.798	221.8	0.394	35.52	63.12
222	2602	23.43	9.62	286	1786	78.40	44.50	0.27	0.798	221.7	0.393	35.55	63.08
223	2603	23.49	9.62	285	1781	78.40	44.50	0.27	0.799	221.7	0.393	35.59	63.08

VI. Conclusions

1. Definite conclusions concerning the relative merits of the diesel cycle with low compression ratio and heated air for aircraft applications cannot be drawn from this work.
2. Improvement in the air utilization of the experimental diesel cylinder must be accomplished before the merits of the diesel cycle can be evaluated in comparison with the present Otto cycle aircraft engines.
3. The computer programs developed give results which are in general agreement with the experimental results. The computer values of indicated specific fuel consumption are somewhat better than the computer values of indicated horsepower, the latter being high by about six percent.

VII. Tables

VIII. Figures

IX. Bibliography

1. Lightweight, Low Compression Aircraft Diesel Engine, by Gaynor, Bottrell, Eagle and Bachle, NASA Report No. CR-135300.

APPENDIX A

Title Sheet of Report No. CR-135300, Final Report for NASA Contract NAS-20051

APPENDIX B

Computer Program Listings

```
10 REM "DIESELA"
20 REM DIESEL CYCLE ANALYSIS
30 REM CV AND CP EQNS DERIVED FROM COMBUSTION CHART
40 DEFINT G,I-K
45 LPRINT CHR$(15)
50 R=53.34:P3=1200*144:CR=9.62
55 PX=P3/144000
60 READ RN,RPM,T1,PI,P6,A1
80 PI=PI*70.7264
90 P6=P6*70.7264
120 T1=T1+460
170 E1=2.0912-8.6669E-4*RPM+2.1226E-7*RPM[2-1.9859E-11*RPM[3
190 X1=(12563+1089*PX-8*PX[2-171*PX[3+35*PX[4)/1E4
200 X2=(17+9806*PX-8783*PX[2+3113*PX[3-387*PX[4)/1E6
240 IFIT>0THEN320
270 LPRINT"P3=";P3/144
290 LPRINT"RUN  RPM   A/F    CR  T1   T5    P1    P6 MV/MF   DF  IMEP  ISFC  IEFF   IHP"
310 FORI=1TO76:LPRINT"-";:NEXT:LPRINT" "
320 PRINT"COMPUTING":PRINT" "
340 VE=E1*(.285+(CR-(P6/PI))/(1.4*(CR-1)))
350 P1=VE*PI
360 V1=.05011*CR/(CR-1)
370 X=X1-X2*(CR-6)
390 AF=A1
400 DF=.58058+.014817*AF-3.9879E-4*AF[2+6.9442E-6*AF[3
410 IT=IT+1
420 FA=1/AF
430 MA=P1*V1/(R*T1):MF=FA*MA:M=MA+MF
440 Q=MF*18200
450 P4=P3:V5=V1
470 W1=P1*V1*(CR[(X-1)-1)/(1-X)
480 V2=V1/CR:V3=V2
500 P2=P1*CR[X
510 T2=T1*CR[(X-1)
520 FR(1)=.2:FR(2)=.3
522 FORI=1TO2
525 MV(I)=FR(I)*MF:T3=P3*V3/(R*(MA+MV(I)))
530 T=(T2+T3)/2
540 CV=.17276+4.4512E-5*T-8.5504E-9*T[2+1.1852E-12*T[3
542 ER(I)=(MV(I)+MA)*CV*(T3-T2)-MV(I)*18200:NEXT
544 IFABS(ER(2))<1E-5THEN560
545 FR=(ER(1)*FR(2)-ER(2)*FR(1))/(ER(1)-ER(2))
547 FR(1)=FR(2):FR(2)=FR:GOTO522
560 MV=MV(2):MP=MF-MV
570 T4(1)=T3+500:T4(2)=T3+1000
572 FORI=1TO2:T=(T3+T4(I))/2
580 CP=.24132+4.4512E-5*T-8.5504E-9*T[2+1.1852E-12*T[3
590 ER(I)=M*CP*(T4(I)-T3)-MP*18200:NEXT
600 IFABS(ER(2))<1E-5THEN640
610 T4=(ER(1)*T4(2)-ER(2)*T4(1))/(ER(1)-ER(2))
615 T4(1)=T4(2):T4(2)=T4:GOTO572
640 V4=M*R*T4/P4
650 T5=T4*(V4/V5)[(X-1)
660 P5=P4*(V4/V5)[X
670 W2=P3*(V4-V3)
680 W3=P4*V4*((V4/V5)[(X-1)-1)/(1-X)
690 W4=P6*(V2-V1)
700 W5=P1*(V1-V2)
710 W=(W1+W2+W3+W4+W5)*DF
720 MEP=W/((V1-V2)*144)
```

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730 HP=W*RPM/66000
740 SFC=MF*RPM*30/HP
750 EFF=W/(Q*7.78)
770 LPRINTUSING"### #### ##.## ##.## ### #### ##.## ##.## #.## #.### ###.# #.### ##.##
##.##";RN,RPM,AF,CR,T1-460, T5-460,P1/70.7264,P6/70.7264,MV/MF,DF,MEP,SFC,EFF,HP
780 GOTO60
790 END
800 DATA 169,2606,284,69.6,48.6,26.32
810 DATA 170,2600,284,69.6,48.6,26.30
820 DATA 171,2600,252,69.6,48.6,27.74
830 DATA 172,2600,252,69.6,48.6,27.82
840 DATA 173,2596,225,69.6,48.6,29.[illegible]
850 DATA 174,2598,226,69.6,48.6,29.33
860 DATA 175,2601,195,69.6,48.6,30.74
870 DATA 176,2602,195,69.6,48.6,30.59
880 DATA 177,2606,165,69.6,48.6,31.74
890 DATA 178,2605,164,69.6,48.6,31.77
900 DATA 179,2598,142,69.6,48.6,32.90
910 DATA 180,2598,142,69.6,48.6,32.90
920 DATA 190,2608,164,69.2,49.2,31.50
930 DATA 191,2604,164,69.2,49.2,31.73
940 DATA 192,2808,165,69.2,49.2,32.59
950 DATA 193,2804,162,69.2,49.2,32.89
960 DATA 194,2405,165,69.2,49.2,30.92
970 DATA 195,2409,165,69.2,49.2,30.96
980 DATA 196,2610,166,69.3,49.3,21.96
990 DATA 197,2607,166,69.3,49.3,22.02
1000 DATA 198,2809,166,69.3,49.3,24.80
1010 DATA 199,2811,166,69.3,49.3,24.67
1020 DATA 200,3005,165,69.3,49.3,25.37
1030 DATA 201,3007,165,69.3,49.3,24.98
1040 DATA 200,3005,165,69.4,49.4,25.39
1050 DATA 201,3007,165,69.4,49.4,25.03
1060 DATA 202,2810,165,69.4,49.4,25.39
1070 DATA 203,2805,165,69.4,49.4,25.52
1080 DATA 204,2599,166,69.4,49.4,25.45
1090 DATA 205,2603,166,69.4,49.4,25.28
1100 DATA 206,2601,166,79.4,47.9,27.94
1110 DATA 207,2601,166,79.4,47.9,27.95
1120 DATA 208,2602,166,69.4,44.4,23.72
1130 DATA 209,2605,165,69.4,44.4,23.78
1140 DATA 210,2599,166,59.4,44.4,19.15
1150 DATA 211,2601,166,59.4,44.4,19.18
1160 DATA 212,2405,165,80.5,49.5,26.71
1170 DATA 213,2412,165,80.5,49.5,26.72
1180 DATA 214,2605,165,67.5,44.5,23.27
1190 DATA 215,2610,164,67.5,44.5,23.24
1200 DATA 216,2598,195,69.0,44.5,22.85
1310 DATA 217,2602,195,69.0,44.5,22.85
1220 DATA 218,2600,224,72.0,44.5,23.19
1230 DATA 219,2603,224,72.0,44.5,23.17
1240 DATA 220,2600,255,75.2,44.5,23.35
1250 DATA 221,2603,255,75.2,44.5,23.37
1260 DATA 222,2602,286,78.4,44.5,23.43
1270 DATA 223,2603,285,78.4,44.5,23.49
```

DIESELA NOMENCLATURE

AF	A/F RATIO
A1	A/F RATIO
CP	CONSTANT PRESSURE SPECIF HEAT
CR	COMPRESSION RATIO
CV	CONSTANT VOLUME SPECIF HEAT
DF	DIAGRAM FACTOR
EFF	INDICATED EFFICIENCY
ER(I)	ERROR TERM
E1	USED TO GET VOLUMETRIC EFFICIENCY
FA	F/A RATIO
FR(I)	FUEL FRACTION
HP	INDICATED HORSEPOWER
M	TOTAL MASS
MA	MASS OF AIR
MEP	INDICATED MEAN EFFECTIVE PRESSURE
MF	MASS OF FUEL
MP	MASS OF FUEL FOR CONSTANT PRESSURE PROCESS
MV	MASS OF FUEL FOR CONSTANT VOLUME PROCESS
PI	INTAKE PRESSURE
PX	PRESSURE TERM IN EXPONENT EQUATION
P1-P6	PRESSURES
Q	TOTAL HEAT OF COMBUSTION
QP	Q USED DURING CONSTANT PRESSURE PROCESS
QV	Q USED DURING CONSTANT VOLUME PROCESS
R	GAS CONSTANT
RN	RUN NUMBER
RPM	REVOLUTIONS PER MINUTE
SFC	INDICATED SPECIFIC FUEL CONSUMPTION
T1-T6	TEMPERATURES
T4(I)	ESTIMATES FOR T4
VE	VOLUMETRIC EFFICIENCY
V1-V5	VOLUMES
W	WORK SUM
W1-W5	PROCESS WORK QUANTITIES
X	POLYTROPIC EXPONENT
X1,X2	TERMS IN POLYTROPIC EXPONENT EQUATION

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10 '"DIESELB"
20 'FUEL=C12H26
30 'FT=TOTAL MOLES FUEL:A=TOTAL UNITS AIR
40 'F=MOLES FUEL FOR CONST VOL:V=TDC VOL
50 'T2=TEMP AT END OF COMP:P3=1200PSIA
60 DEFINT I,J,K,M,Z
70 DIMA(15,16),B(15,16),X(16),Y(15),SS(14,4),D(16),YR(15)
80 DIML1(14),L2(14),NE(14),HF(14),CV(14),UR(14),HR(14)
90 DIMH(15),H1(14),H2(14),H3(14),H4(14),H5(14),U(15)
100 DIMC(14),C1(14),C2(14),C3(14),C4(14),C5(14),S$(15)
110 DIMS(14),S1(14),S2(14),S3(14),S4(14),S5(14),Q(9),QO(9)
120 IN=16:M=15:X(16)=0:D(16)=0:A=.01727:HF=-84.2
121 LC=2.302585:R=1.98726:RB=.082055
125 INPUT"CR,T2-DEG K,A/F,PMAX-PSIA";CR,T2,AF,PM
126 V=1/CR:P3=PM/14.696:FT=138*A/(170*AF)
130 'READ PRODUCTS
140 RESTORE:FORJ=1TO15:READS$(J):NEXT
150 'READ NUMBER OF ATOMS OF C,H,N,O IN EACH SPECIE
160 FORJ=1TO14:FORI=1TO4:READSS(J,I):NEXTI:NEXTJ
170 'READ COEFF FOR EQUIL EQNS
180 FORI=1TO9:FORJ=1TO14:READA(I,J):NEXTJ:NEXTI
190 'READ CONST FOR EQUIL CONST EQN
200 FORJ=1TO14:READL1(J),L2(J):NEXT
210 'READ THERMO-CHEM DATA:H=ENTHALPY,C=SPEC HEAT,S=ENTROPY
220 FORJ=1TO14
230 READNE(J),HF(J),H1(J),H2(J),H3(J),H4(J),H5(J)
240 READC1(J),C2(J),C3(J),C4(J),C5(J)
250 READS1(J),S2(J),S3(J),S4(J),S5(J):NEXT
260 'PROCESS:IF K=0 V=CONST,K=1 P=CONST
280 T3=1200:T4=2100:F=1.22E-4
290 K=0:T=T2:Z=0
300 'INITIALIZE NO MOLES OF REACT FOR V=CONST
310 YR(1)=0:YR(2)=0:YR(3)=0:YR(4)=3.76*A:YR(5)=0:YR(6)=0
320 YR(7)=0:YR(8)=0:YR(9)=A:YR(10)=0:YR(11)=0:YR(12)=0
330 YR(13)=0:YR(14)=0
340 'READ NO MOLES OF PROD FOR FIRST ITERATION
350 FORJ=1TO14:READY(J):NEXT
360 'INTERNAL ENERGY OR ENTHALPY OF REACT
370 UR=0:HR=0:YR(10)=0
380 FORJ=1TO14
390 HR(J)=100*NE(J)+HF(J)+H1(J)+H2(J)*T+H3(J)*T[2
400 HR(J)=HR(J)+H4(J)*T[3+H5(J)*T[4
410 IFK=1THEN430
420 UR(J)=HR(J)-R*T/1000:UR=UR+YR(J)*UR(J):GOTO440
430 HR=HR+YR(J)*HR(J)
440 NEXTJ
450 HR=HR+F*(HF+2500)
460 IFK=0THENT=T3:Y(15)=T3:GOTO500:ELSET=T4:Y(15)=T4
470 'READ NO MOLES OF PROD FOR FIRST ITER FOR P=CONST
480 FORI=1TO14:READY(I):NEXT
490 'TOTAL NO MOLES OF C,H,N,O OF REACT
500 YC=0:YH=0:YN=0:YO=0
510 FORJ=1TO14:YC=YC+SS(J,1)*YR(J):YH=YH+SS(J,2)*YR(J)
520 YN=YN+SS(J,3)*YR(J):YO=YO+SS(J,4)*YR(J):NEXT
530 YC=YC+12*F:YH=YH+26*F
540 'TOTAL NO MOLES OF C,H,N,O OF PROD
550 C=0:H=0:N=0:O=0:Y(10)=0:YP=0
560 FORJ=1TO14
570 C=C+SS(J,1)*Y(J):H=H+SS(J,2)*Y(J):N=N+SS(J,3)*Y(J)
580 O=O+SS(J,4)*Y(J):YP=YP+Y(J):NEXT
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590 'PRESSURE
600 P=YP*RB*T/V
610 'COEF OF ATOM BAL EQNS
620 FORI=10TO13:FORJ=1TO14:A(I,J)=SS(J,I-9)*Y(J):NEXTJ:NEXTI
630 'COEF OF XF FOR ATOM BAL AND PRESS EQNS
640 IFK=1THEN670
650 A(10,10)=-12*F*C/YC:A(11,10)=-26*F*H/YH
660 A(12,10)=0:A(13,10)=0:A(14,10)=0:GOTO690
670 A(10,10)=0:A(11,10)=0:A(12,10)=0:A(13,10)=0:A(15,10)=0
680 'COEF OF PRESS EQN
690 FORJ=1TO14:A(14,J)=Y(J):NEXT
700 'ERROR CONSTANTS
710 D(10)=LOG(C/YC)/LC:D(11)=LOG(H/YH)/LC
720 D(12)=LOG(N/YN)/LC:D(13)=LOG(O/YO)/LC:D(14)=LOG(P/P3)/LC
730 A(10,16)=-C*D(10):A(11,16)=-H*D(11)
740 A(12,16)=-N*D(12):A(13,16)=-O*D(13):A(14,16)=-YP*D(14)
750 HP=0:UP=0:SP=0
760 'ENTHALPY OR INTERNAL ENERGY OF PROD
770 FORJ=1TO14
780 H(J)=100*NE(J)+HF(J)+H1(J)+H2(J)*T+H3(J)*T[2
790 H(J)=H(J)+H4(J)*T[3+H5(J)*T[4
800 GOTO840
810 'ENTROPY
820 S(J)=S1(J)+S2(J)*T+S3(J)*T[2+S4(J)*T[3+S5(J)*T[4
830 S(J)=(S(J)-R*LOG(Y(J)*RB*T/V))/1000
840 IFK=1THEN870
850 U(J)=H(J)-R*T/1000:UP=UP+Y(J)*U(J)
860 GOTO880
870 HP=HP+Y(J)*H(J)
880 NEXTJ
890 'COEF OF ENERGY EQN
900 IFK=1THEN920
910 FORJ=1TO14:A(15,J)=Y(J)*U(J):NEXT:GOTO960
920 FORJ=1TO14:A(15,J)=Y(J)*H(J):NEXT
930 'COEF OF XV IN PRESS EQN FOR P=CONST
940 A(14,10)=-YP
950 'COEF. OF XT IN PRESSURE EQN.
960 A(14,15)=YP
970 'INTERNAL ENERGY OF PRODUCTS FOR V=CONST
980 IFK=1THEN1030
990 UF=HF+2500:UP=UP-F*UF
1000 'COEF OF XF IN ENERGY EQN FOR V=CONST
1010 A(15,10)=-UF*F:GOTO1050
1020 'COEF OF XV IN ENERGY EQN FOR P=CONST
1030 A(15,10)=0
1040 'COEF OF XT AND XV IN EQUIL EQN
1050 QD=R*T/1000
1060 FORI=1TO9:A(I,15)=0:A(I,10)=0
1070 FORJ=1TO14
1080 'COEF OF XT IN EQUIL EQN
1090 A(I,15)=A(I,15)+A(I,J)-A(I,J)*H(J)/QD
1100 IFK=0THEN1120
1110 A(I,10)=A(I,10)-A(I,J)
1120 NEXTJ:NEXTI
1130 CV=0:CP=0
1140 'COEF OF XT IN ENERGY EQN
1150 FORJ=1TO14
1160 C(J)=C1(J)+C2(J)*T+C3(J)*T[2+C4(J)*T[3+C5(J)*T[4
1170 IFK=1THEN1190
1180 CV(J)=C(J)-R:CV=CV+Y(J)*CV(J):GOTO1200
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1190 CP=CP+Y(J)*C(J)
1200 NEXTJ
1210 IFK=1THEN1240
1220 A(15,15)=CV*T/1000:D(15)=LOG(UP/UR)/LC
1230 A(15,16)=-UP*D(15):GOTO1270
1240 A(15,15)=CP*T/1000:D(15)=LOG(HP/HR)/LC
1250 A(15,16)=-HP*D(15)
1260 'ERROR CONSTANT FOR EQUIL EQN
1270 FORI=1TO9
1280 Q(I)=LOG(Y(I))-SS(I,1)*LOG(Y(14))-SS(I,2)*LOG(Y(11))
1290 Q(I)=Q(I)-SS(I,3)*LOG(Y(12))-SS(I,4)*LOG(Y(13))
1300 Q(I)=Q(I)+(1-SS(I,1)-SS(I,2)-SS(I,3)-SS(I,4)) *LOG(RB*T/V)
1310 Q0(I)=L1(I)-L2(I)/T
1320 Q0(I)=Q0(I)-SS(I,1)*(L1(14)-L2(14)/T)-SS(I,2) *(L1(11)-L2(11)/T)
1330 Q0(I)=Q0(I)-SS(I,3)*(L1(12)-L2(12)/T)-SS(I,4) *(L1(13)-L2(13)/T)
1340 D(I)=Q(I)/LC-Q0(I):A(I,16)=-D(I):NEXT
1350 EP=0:EQ=0
1360 FORI=1TO 3:EQ=EQ+ABS(D(I)):NEXT
1370 FORI=4TO15:EP=EP+ABS(D(I)):NEXT
1380 IFK=0THEN1400
1390 EP=EP+EQ
1400 PRINTEP,T
1410 IFEP<.0005THEN1750
1420 A(10,15)=0:A(11,15)=0:A(12,15)=0:A(13,15)=0
1430 'MATRIX SOLUTION
1440 FORI=1TOM:X(I)=0:FORJ=1TOIN:B(I,J)=0:NEXTJ:NEXTI
1450 FORI=1TOM:B(I,1)=A(I,1):NEXT
1460 FORJ=2TOIN:B(1,J)=A(1,J)/A(1,1):NEXT
1470 FORIC=2TOM:J=IC
1480 FORI=JTOM:SUM=0:J1=J-1
1490 FORIK=1TOJ1:SUM=SUM+B(I,IK)*B(IK,J):NEXTIK
1500 B(I,J)=A(I,J)-SUM:NEXTI
1510 I=J:I1=I+1
1520 FORJ=I1TOIN:SUM=0:J1=J-1
1530 FORIK=1TOJ1:SUM=SUM+B(I,IK)*B(IK,J):NEXTIK
1540 B(I,J)=(A(I,J)-SUM)/B(I,I):NEXTJ:NEXTIC
1550 IFZ<3THENL=.06ELSEL=.1
1560 X(M)=B(M,IN):IFX(M)>LLETX(M)=L
1570 IFX(M)<-LLETX(M)=-L
1580 Y(M)=Y(M)*10[X(M):IFY(M)<900LETY(M)=900
1590 IFY(M)>3500LETY(M)=3500
1600 T=Y(M)
1610 FORIL=2TOM:I=1-IL+M:SUM=0:I1=I+1
1620 FORIK=I1TOM:SUM=SUM+B(I,IK)*X(IK):NEXTIK
1630 X(I)=B(I,IN)-SUM:IFX(I)>36LETX(I)=36
1635 IF X(I)<-36LETX(I)=-36
1640 Y(I)=Y(I)*10[X(I):IFY(I)<1E-38LETY(I)=1E-38
1650 IFY(I)>3.76*ALETY(I)=3.76*A
1660 NEXTIL
1670 Z=Z+1:IFK=1THEN1690
1680 F=F*10[X(10):IFF<FT/50LETF=FT/50
1685 IFF>FTLETF=FT
1687 GOTO550
1690 V=V*10[X(10):IFV<1/CRLETV=1/CR
1700 IFV>1LETV=1
1710 GOTO550
1750 YP=0:XP=0
1760 FORJ=1TO14:YP=YP+Y(J):NEXT
1770 FORJ=1TO14:X(J)=Y(J)/YP:XP=XP+X(J):NEXT
1780 IFK=1THEN1970
```

```
1785 LPRINT"CR=";CR,"T2=";T2,"A/F=";AF,"PMAX=";PM
1790 LPRINT"CONSTANT VOLUME PROCESS"
1800 LPRINT"INPUT:NO MOLES OF FUEL=";FT
1810 LPRINT TAB(6)"NO MOLES OF AIR=";A*4.76
1820 LPRINT TAB(6)"PEAK PRESS P3 =";P;"ATM"
1830 LPRINT TAB(6)"TEMPERATURE T2=";T2
1840 LPRINT"Y=NO OF MOLES OF PRODUCTS"
1850 LPRINT"X=MOLE FRACTION OF PRODUTS"
1860 FOR J=1TO14
1870 LPRINT "Y(";S$(J);")=";Y(J);TAB(21)"X(";S$(J);")=";X(J)
1880 NEXTJ
1890 LPRINT"YTOT=";YP;TAB(21)"VOLUME=";V
1900 LPRINT"TEMP T3=";T;TAB(21)"UR=";UR
1910 LPRINT"FUEL=";F;TAB(21)"UP=";UP
1920 LPRINT"PRESSURE=";P;TAB(21)"ITERATION=";Z
1930 LPRINT"TOTAL ERROR=";EP:LPRINT"   ":LPRINT"   "
1940 'INITIALIZE NO MOLE OF REACTANT FOR P=CONST PROCESS
1950 FORJ=1TO14:YR(J)=Y(J):NEXT
1960 F=FT-F:K=1:Z=0:V=.18:GOTO370
1970 LPRINT"CONSTANT PRESSURE PROCESS"
1980 FORJ=1TO14
1990 LPRINT"Y(";S$(J);")=";Y(J);TAB(21)"X(";S$(J);")=";X(J)
2000 NEXTJ
2010 LPRINT"YTOT=";YP;TAB(21)"VOLUME=";V
2020 LPRINT"TEMP T4=";T;TAB(21)"HR=";HR
2030 LPRINT"FUEL=";F;TAB(21)"HP=";HP
2040 LPRINT"PRESSURE =";P;TAB(21)"ITERATION=";Z
2050 LPRINT"TOTAL ERROR=";EP
2055 GOTO125
2070 DATA CO2,CO,CH4,N2,NO,H2O,H2,OH,O2,F,H,N,O,C,T
2080 DATA 1,0,0,2,1,0,0,1,1,4,0,0,0,2,0,0,0,1,1,0,2,0,1
2090 DATA 0,2,0,0,0,1,0,1,0,0,0,2,0,0,0,0,0,1,0,0,0,0,1,0
2100 DATA 0,0,0,1,1,0,0,0
2110 DATA 1,0,0,0,0,0,0,0,0,0,0,-2,-1
2120 DATA 0,1,0,0,0,0,0,0,0,0,0,0,-1,-1
2130 DATA 0,0,1,0,0,0,0,0,0,0,-4,0,0,-1
2140 DATA 0,0,0,1,0,0,0,0,0,0,0,-2,0,0
2150 DATA 0,0,0,0,1,0,0,0,0,0,0,-1,-1,0
2160 DATA 0,0,0,0,0,1,0,0,0,0,-2,0,-1,0
2170 DATA 0,0,0,0,0,0,1,0,0,0,-2,0,0,0
2180 DATA 0,0,0,0,0,0,0,1,0,0,-1,0,-1,0
2190 DATA 0,0,0,0,0,0,0,0,1,0,0,0,-2,0
2200 DATA -.0295997,-20764.8,4.2918,-6345.6,-5.8028,-4790.4
2210 DATA 0,0,.6574,4711.2,-3.0466,-13168.8,0,0,.7068,1886.4
2220 DATA 0,0,0,0,3.1626,11896.8,3.514,25116
2230 DATA 3.503,13356,8.1622,37281.6
2240 DATA 2,-94.054,-4.04934,.0106409,1.66486E-6, -2.97619E-10,2.12058E-14
2250 DATA 8.65961,6.62203E-3,-2.80545E-6,5.50571E-10, -4.04973E-14
2260 DATA 47.3063,.0224858,-6.43573E-6,1.06715E-9, -7.18642E-14
2270 DATA 1.5,-26.417,-2.21792,6.65945E-3,8.895E-7, -1.60617E-10,1.14865E-14
2280 DATA 5.81533,3.20923E-3,-1.32846E-6,2.55813E-10, -1.85551E-14
2290 DATA 45.6148,.0138031,-4.00914E-6,6.70106E-10, -4.53569E-14
2300 DATA 3,-17.895,-4.12819,7.85264E-3,6.44417E-6, -1.13465E-9,7.77547E-14
2310 DATA 2.29288,.0222002,-8.84428E-6,1.64138E-9, -1.16043E-13
2320 DATA 37.5038,.0268812,-6.04799E-6,8.54565E-10, -5.18365E-14
2330 DATA 1,0,-2.08601,6.39974E-3,9.78717E-7,-1.7702E-10, 1.26646E-14
2340 DATA 5.61035,3.31765E-3,-1.34883E-6,2.56255E-10, -1.84078E-14
2350 DATA 44.0463,.0139597,-4.16865E-6,7.18432E-10, -5.00693E-14
2360 DATA 1,21.58,-2.3971,7.10077E-3,7.27649E-7, -1.29337E-10,9.13029E-15
2370 DATA 6.2401,2.87745E-3,-1.20965E-6,2.35588E-10, -1.72297E-14
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ORIGINAL PAGE IS
OF POOR QUALITY

```
2380 DATA 48.584,.0144177,-4.30522E-6,7.35191E-10, -5.06584E-14
2390 DATA 1.5,-57.798,-1.74099,5.66898E-3,2.6696E-6, -4.16138E-10,2.65073E-14
2400 DATA 5.21619,6.19274E-3,-1.79861E-6,2.52241E-10, -1.36954E-14
2410 DATA 43.2465,.0156744,-3.89475E-6,6.08863E-10, -4.00555E-14
2420 DATA 1,0,-1.39667,5.4312E-3,1.04227E-6,-1.41029E-10, 9.13029E-15
2430 DATA 6.08244,1.11889E-3,7.64342E-8,-7.15413E-11, 8.32035E-15
2440 DATA 30.5792,.0119128,-3.2945E-6,5.48002E-10, -3.71102E-14
2450 DATA 1,9.33,-1.57162,5.69288E-3,1.01526E-6, -1.46545E-10,8.83577E-15
2460 DATA 5.72647,1.99422E-3,-4.27002E-7,3.39192E-11,0
2470 DATA 43.0976,.0123579,-3.47117E-6,5.79225E-10, -3.94664E-14
2480 DATA 1,0,-2.60987,7.66459E-3,3.84913E-7,-1.21984E-11, -8.83577E-16
2490 DATA 7.12922,1.62729E-3,-5.17909E-7,1.09964E-10, -9.57208E-15
2500 DATA 47.1106,.0148638,-4.51712E-6,7.94175E-10, -5.59598E-14
2510 DATA 0,0,0,0,0,0,0
2520 DATA 0,0,0,0,0
2530 DATA 0,0,0,0,0
2540 DATA .5,52.102,-1.48108,4.96807E-3,-1.21905E-11,0,0
2550 DATA 4.968,0,0,0,0
2560 DATA 26.6523,9.23922E-3,-2.97998E-6,5.3166E-10, -3.76993E-14
2570 DATA .5,112.965,-1.45182,4.89058E-3,7.43347E-8, -3.08721E-11,4.71241E-15
2580 DATA 4.86307,2.16256E-4,-1.45303E-7,3.50204E-11, -1.69352E-15
2590 DATA 35.9583,9.08062E-3,-2.87709E-6,5.03335E-10, -3.4754E-14
2600 DATA .5,59.559,-1.47692,5.06465E-3,-4.23555E-8, 6.02427E-12,2.94526E-16
2610 DATA 5.03035,-1.64497E-5,-2.81153E-8,1.40069E-11, -1.25173E-15
2620 DATA 37.9917,8.99493E-3,-2.81594E-6,4.88005E-10, -3.35759E-14
2630 DATA 1,170.886,-1.52889,5.11106E-3,-1.32952E-7, 4.51027E-11,-3.38704E-15
2640 DATA 5.09745,-2.2207E-4,9.69728E-8,-1.15443E-12, -1.32537E-15
2650 DATA 37.1575,9.00799E-3,-2.85048E-6,5.04278E-10, -3.53431E-14
2660 DATA 1.5E-3,7.5E-12,1E-38,.065,1.7E-5,1.6E-3,4.8E-12
2670 DATA 3.6E-8,.015,0,1.2E-14,3.0E-20,9.0E-11,1E-38
2680 DATA 6.6E-3,7.3E-6,1.0E-22,.065,5.5E-4,7.1E-3,1.7E-6
2690 DATA 6.9E-5,6.9E-3,0,1.3E-7,3.0E-11,3.7E-6,3.6E-23
2700 END
```

DIESELB NOMENCLATURE

A	TOTAL UNITS OF AIR (O2+3.76 N2)
A(I,J)	MATRIX ELEMENTS
AF	AIR FUEL RATIO
B(I,J)	MATRIX ELEMENTS
C	C-ATOMS IN PRODUCTS
C(J)	SPECIFIC HEAT OF PRODUCT J
CP	SPECIFIC HEAT OF PRODUCTS
CR	COMPRESSION RATIO
CV	SPECIFIC HEAT OF PRODUCTS
CV(J)	SPECIF HEAT OF SPECIE J
C1-C5(J)	SPEC HEAT EQUATION CONSTANTS
D(I)	DIFFERENCE FACTOR
EP	ERROR PARAMETER
EQ	ERROR PARAMETER
F	MOLES FUEL FOR CONSTANT VOLUME PROCESS
FT	TOTAL MOLES OF FUEL
H	H-ATOMS IN PRODUCTS
H(J)	ENTHALPY OF PRODUCT J
HF	ENTHALPY OF COMBUSTION
HF(J)	ENTHALPY OF FORMATION OF SPECIE J
HP	ENTHALPY OF PRODUCTS
HR	ENTHALPY OF REACTANTS
HR(J)	ENTHALPY OF REACTANT J
H1-H5(J)	ENTHALPY EQUATION CONSTANTS
I,IC,IK	INTEGERS
IL,IN,I1	INTEGERS
J,J1,K	INTEGERS
L	ERROR LIMIT
LC	LOG CONVERSION CONSTANT
L1-L2(I)	EQUILIBRIUM EQUATION CONSTANTS
M	INTEGER
N	N-ATOMS IN PRODUCTS
NE(J)	MOLES OF ELEMENTS IN SPECIE J
O	O-ATOMS IN PRODUCTS
P,P3	PRESSURE
Q(I)	CALCULATED EQUIL CONSTANT FOR FORMATION OF I
QD	R*T/1000
QO(I)	EQUILIBRIUM CONSTANT FROM JANAF TABLES
R,RB	GAS CONSTANTS
S(J)	ENTROPY OF PRODUCT J
SP	ENTROPY OF PRODUCTS
SS(I,J)	NUMBER OF ATOMS OF TYPE I IN SPECIE J
S1-S5(J)	ENTROPY EQUATION CONSTANTS
S$(J)	SPECIE SYMBOL
T,T2-T4	TEMPERATURES
U(J)	INTERNAL ENERGY OF SPECIE J
UF	INTERNAL ENERGY OF FUEL
UP	INTERNAL ENERGY OF PRODUCTS
UR	INTERNAL ENERGY OF REACTANTS
UR(J)	INTERNAL ENERGY OF REACTANT J
V	TOP DEAD CENTER VOLUME
X(I)	MATRIX SOLUTIONS
XP	TOTAL MOLE FRACTION OF PRODUCTS
Y(J)	MOLES OF PRODUCT J
YC,YH	C- AND H- ATOMS IN REACTANTS
YN,YO	N- AND O- ATOMS IN REACTANTS

YP	TOTAL MOLES OF PRODUCTS
YR(I)	MOLES OF REACTANT I
Z	NUMBER OF ITERATIONS

```
CR= 10            T2= 777           A/F= 24           PMAX= 1200
CONSTANT VOLUME PROCESS
INPUT:NO MOLES OF FUEL= 5.84132E-04
      NO MOLES OF AIR= .0822052
      PEAK PRESS P3 = 81.6549 ATM
      TEMPERATURE T2= 777
Y=NO OF MOLES OF PRODUCTS
X=MOLE FRACTION OF PRODUTS
Y(CO2)= 1.46337E-03  X(CO2)= .0176314
Y(CO)= 7.51498E-12   X(CO)= 9.05444E-11
Y(CH4)= 1E-38        X(CH4)= 1.20485E-37
Y(N2)= .0649267      X(N2)= .782271
Y(NO)= 1.66875E-05   X(NO)= 2.0106E-04
Y(H2O)= .0015853     X(H2O)= .0191005
Y(H2)= 4.77274E-12   X(H2)= 5.75045E-11
Y(OH)= 3.63892E-08   X(OH)= 4.38437E-07
Y(O2)= .0150056      X(O2)= .180796
Y(F)= 0              X(F)= 0
Y(H)= 1.21079E-14    X(H)= 1.45883E-13
Y(N)= 2.99162E-20    X(N)= 3.60446E-19
Y(O)= 9.01939E-11    X(O)= 1.0867E-09
Y(C)= 1E-38          X(C)= 1.20485E-37
YTOT= .0829977       VOLUME= .1
TEMP T3= 1198.98     UR= 8.37599
FUEL= 1.21754E-04    UP= 8.37599
PRESSURE= 81.6549    ITERATION= 3
TOTAL ERROR= 4.1348E-04


CONSTANT PRESSURE PROCESS
Y(CO2)= 6.99839E-03  X(CO2)= .0813413
Y(CO)= 1.35258E-05   X(CO)= 1.57208E-04
Y(CH4)= 6.65312E-22  X(CH4)= 7.73283E-21
Y(N2)= .0646316      X(N2)= .751204
Y(NO)= 6.06853E-04   X(NO)= 7.05336E-03
Y(H2O)= 7.54721E-03  X(H2O)= .0877201
Y(H2)= 2.92444E-06   X(H2)= 3.39903E-05
Y(OH)= 9.19496E-05   X(OH)= 1.06872E-03
Y(O2)= 6.13907E-03   X(O2)= .0713535
Y(F)= 0              X(F)= 0
Y(H)= 2.61932E-07    X(H)= 3.04439E-06
Y(N)= 6.96451E-11    X(N)= 8.09476E-10
Y(O)= 5.57688E-06    X(O)= 6.48192E-05
Y(C)= 3.09552E-22    X(C)= 3.59788E-21
YTOT= .0860374       VOLUME= .187398
TEMP T4= 2167.47     HR= 9.9849
FUEL= 4.62379E-04    HP= 9.98489
PRESSURE = 81.6549   ITERATION= 3
TOTAL ERROR= 3.19628E-05
```